

Performance, Combustion and Emission Evaluation of Fish and Corn Oil as substitute fuel in Direct Injection C. I. Engine

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Abstract- The indiscriminate usage of fossil fuels in many countries has led to an increased interest in the search for suitable alternative fuels. Methyl Esters of Vegetable oils and Animal fats are found to be good alternative, renewable and environmental friendly fuels for C.I. engines.

This paper presents the results of investigation carried out in studying the properties and behavior of methyl esters of corn seed oil, fish oil and its blends with diesel fuel in a C I Engine. Engine tests have been carried out to determine the performance, emission and combustion characteristics of the above mentioned fuels.

The tests have been carried out in a 4-stroke, computerized, single cylinder, constant speed, direct injection diesel engine at different loads. The loads were varied from 0% to 100% of the maximum load in steps of 25%. The Methyl Ester blends of 10%, 20% and 30% by volume with diesel were used. The engine test parameters were recorded with the help of engine analysis software and were studied with the help of graphs.

The results showed that the properties of the above mentioned oils are comparable with conventional diesel. The 20% blend performed well in running a diesel engine at a constant speed of 1500 rpm. It substantially reduced the emissions with acceptable efficiency. Hence the oils can be used as suitable additives for diesel in compression ignition engine.

Keywords – Fish Oil Methyl Ester, Corn Seed Oil Methyl Ester, Brake Thermal Efficiency, Brake Specific Fuel Consumption, Peak Pressure, Heat Release Rate, Exhaust Gas Temperature, Unburnt Hydrocarbons.

I. INTRODUCTION

Diesel engine is a popular prime mover for surface transportation, agricultural machinery and industries. More than 6.5 million Diesel engines are being used in the Indian agricultural sectors for various activities. Import of petroleum products is a major drain on our foreign exchange sources and with growing demand in future years the situation is likely to become worse. Hence, it has become imperative to find suitable alternative fuels, which is indigenous [1, 3,11]. Biodiesel fuels seem to be providing a promising alternative solution to all the present problems. Biodiesel can be produced using renewable resources such as vegetable oils (like corn seed oil, palm oil) and animal fats (like poultry fat, Fish oils) or used cooking oils from the food industry, restaurants or domestic kitchens.

Though animal fats and vegetable oils originate from diverse sources, a comparison between animal fat oil like fish oil and an edible vegetable oil like corn seed oil as biodiesel gives us an insight to the major and minor differences among their properties and their uses when run as a biodiesel in its transesterified form. Hence, this work shows the difference and comparison between animal fat oil and an edible vegetable oil when used as biodiesel keeping petroleum diesel as the reference.

The primary problem associated with straight animal fat oil or vegetable oil as a fuel in a Diesel engines is caused by high viscosity and low volatility, which causes improper atomization of fuel during injection leading to incomplete combustion and results in formation of deposits on the injectors and cylinder heads, leading to poor performance, higher emissions and reduced engine life [1, 3]. The high viscosity of these raw oils can be reduced by using transesterification process. The concept of transesterification process of raw oils with an alcohol (methyl or ethyl) provides a clean burning fuel (commonly known as biodiesel) having less viscosity. At industrial level, biodiesel is normally produced by this transesterification process, a chemical process in which triglyceride react with an alcohol (methyl or ethyl) in the presence of an alkali catalyst (usually NaOH or KOH in proportions of about 1% weight of oil) to form fatty acid alkyl esters (biodiesel) and glycerol (by-product) [5,6,10]. This occurs in a multiple reaction process including three reversible steps in series, where triglycerides are converted to diglycerides, then diglycerides are converted to mono-glycerides, and monoglycerides are converted to esters and glycerol. The fish oil and the corn seed oil obtained after this transesterification process is usually referred to as Fish Oil Methyl Ester (FOME) and Corn Seed oil Methyl Ester (CSME) respectively[5,6]. The main advantage of this biodiesel is that many of its properties are quite close to that of Diesel [1, 3,13]. There are numerous other advantages of biodiesel compared to Diesel, including its biodegradability, higher flash point, i.e. less flammability, and it is a clean burning fuel, allowing for 78 % reduction in CO₂ lifecycle emissions compared to petroleum Diesel [5, 6]. Hence, the potential use of biodiesel fuel using FOME and CSME is presented in this paper and Table: 1 enlists the various properties of FOME and CSME when compared to

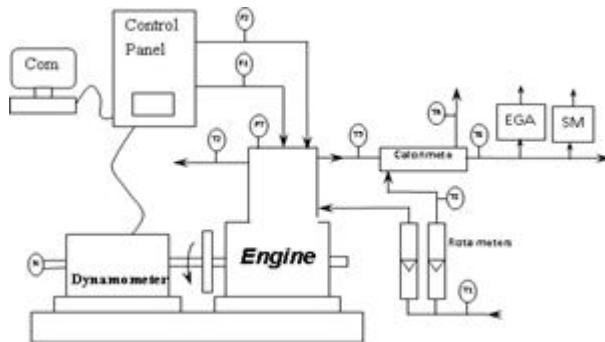


Fig 1: Schematic Representation of the Experimental Setup

1. Water inlet to the calorimeter and engine (T_1 °C)
2. Water outlet from the engine jacket (T_2 °C)
3. Water outlet from the calorimeter (T_3 °C)
4. Exhaust gas inlet to the calorimeter (T_4 °C)
5. Exhaust gas out let from the calorimeter (T_5 °C)
6. Atmospheric air temperature ($(T_6$ °C)
7. Fuel flow
8. Pressure Transducer, EGA. Exhaust gas analyzer, SM. Smoke Meter.

TABLE I. PROPERTIES OF DIESEL, FOME, AND CSME.

Property	Diesel	Raw CSO	Raw FO	CSME	FOME
Density at 15 °C (kg/m ³)	850	920	923	870	883
Kinematic viscosity at 40 °C, cSt	2.5	35	29.59	4.52	6.10
Iodine value (g/100goil)	38.30	120-130	158	126.6	85.96
Acid value (mgKOH/goil)	0.34	10.7	2.24	0.47	-
Higher heating value (MJ/kg)	43.350	36.3	39.01	38.825	41.60
Flash Point (°C)	56	320	165	254	110

Diesel fuel.

II. TRANSESTERIFICATION

A Transesterification is process of conversion of one ester into another, (E.g. A glyceride ester into alkyl ester). Transesterification process converts the triple chain triglycerides to three single chain methyl ester molecules with glycerin as a byproduct as shown in Fig 2, but the chain lengths of the fatty acids themselves remains same (R_1 , R_2 , R_3). Therefore the overall carbon atoms per fatty acid molecule in the oils and fats reduce.

By this process the methyl ester molecule will have lower viscosity than raw oils and fats.

Transesterification process occurs in three stages. First, one fatty acid chain breaks off the triglyceride molecule and bonds with methanol to form methyl ester molecule, leaving a diglyceride molecule (two chains of fatty acids bound by glycerine). Then a fatty acid chain breaks off the diglyceride molecule and bonds with methanol to form another methyl ester molecule, leaving a monoglyceride molecule. Finally the monoglycerides are converted to methyl esters.

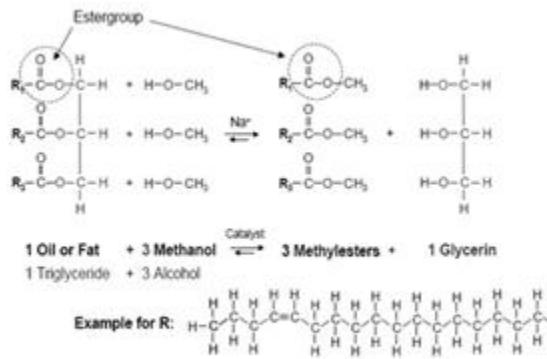


Fig 2: Transesterification of Oils and Fats

III. PROPERTIES OF FUEL

Before conducting the performance test, important properties such as density, kinematic viscosity, flash point, fire point, and calorific value of corn seed oil, its methyl esters and its blends are determined. The table 1 gives the comparison of properties of the methyl esters of corn seed oil and fish oil with conventional petroleum diesel. The kinematic viscosity of raw corn seed oil and Fish oil was found to be 14 and 11.84 times that of diesel at 40R°C. After Transesterification, the kinematic viscosity was reduced to 1.81 and 2.4 times that of diesel respectively. It is further reduced with increase in percentage of diesel in the blend. Similar reduction in density was also observed. However, the calorific value of the CSME and FOME were found to be 38825 kJ/kg and 41600 kJ/kg which is less than the calorific value of diesel (43350 kJ/kg) but higher compared to their raw type. As the percentage of biodiesel in the blend is increased, the overall calorific value decreases. The flash points of corn seed and fish oil biodiesel was found to be greater than 100R°C, which is safe for storage and handling purpose.

IV. EXPERIMENTATION

The experiments were conducted on a computerized diesel engine test rig shown in Fig 1. Kirloskar made single cylinder, 4-stroke, naturally aspirated direct injection, water cooled diesel engine of 5HP rated power at 1500 rpm was directly coupled to an eddy current dynamometer (Table 2.). The engine and the dynamometer were interfaced to a control panel which is connected to a digital computer. The computerized test rig was used for recording the test parameters such as fuel flow rate, temperature, air flow rate, load etc. and for calculating the engine performance characteristics such as brake power, brake thermal efficiency, brake specific fuel consumption, volumetric efficiency etc. The calorific value and the density of the particular fuel were fed to the engine software for calculating the performance parameters. Similarly combustion characteristics such as heat release rate, peak pressure, etc. were also calculated. Exhaust emissions such as NOX, UBHC, CO, and EGT were measured with a MRU make exhaust gas analyzer and smoke opacity using an AVL smoke meter.

The whole set of experiments were conducted at the rated speed of 1500 rpm, compression ratio 16.5:1 and injection

timing of 27R" BTDC. The tests were conducted at no-load, 25%, 50%, 75% and 100% of maximum load condition with B10, B20 and B30 blends. The maximum load on the engine was restricted to 20Nm although it could have been pushed to 25Nm. This was done in order to obtain optimum results without over stressing the engine. The data recording was done after the experiment was carried out for three times to obtain a repeatability of values for each blend.

TABLE II. SPECIFICATIONS OF ENGINE

Make	Kirloskar
Capacity	5HP
Compression Ratio	16.5:1
Cylinder Bore	80mm
Stroke	110mm
Cylinder Capacity	553cc
Cooling	Water Cooled
Loading	Eddy Current Dynamometer
Speed	1500RPM
Maximum Loading	20 N-m
Injection Pressure	200 bar
No. of Cylinders	1

V. RESULTS AND DISCUSSIONS

The engine tests were conducted with FOME blends and CSME blends for no load to full condition and the corresponding performance, emission and combustion characteristics were studied in comparison with Diesel fuel. All the tests were conducted under the same conditions and repeated for three times to obtain consistent values. From the results of these tests it was noticed that the FOME and CSME blend showed better performance and combustion characteristics compared to diesel. Also it was found that 20% CSME and 20% FOME were comparatively better among all other biodiesel blends.

VI. PERFORMANCE ANALYSIS

A. Brake Thermal Efficiency (BTE)–

The variation of BTE with load for all the fuels is shown in Fig 3. Generally the BTE is improved with increase in load. It is observed that all blends of CSME and B20 FOME gave higher efficiency than Diesel fuel at all loading conditions.

Among the FOME blends the B20 FOME showed the highest BTE with an increase of 27.77% and 9.21% at 0Nm and 20Nm respectively with respect to diesel. And among

the CSME blends the B20 blend showed maximum increase in BTE with respect to Diesel by 53.05% and 20.63% at 0Nm and 20Nm loads respectively. Also the BTE of CSME B30 shows very little variations in comparison to the CSME B20 fuel. The B20 blends show better BTE because their area coverage of spray in the combustion chamber is higher compared to other blends hence effective air utilization takes place resulting in better combustion [4, 5, 12].

The higher blends of FOME generate coarse spray due to increase in viscosity of the blend. This leads to decrease in area of spray formed, resulting in improper combustion and hence lower BTE [4, 5,]. On the other hand blends of CSME do not show this characteristics because the kinematic viscosity of CSME is lesser compared to FOME, hence showing negligible variations in BTE with respect to the B20 and B30 blends.

B. Brake Specific Fuel Consumption (BSFC)–

The variation of BSFC with load of all the fuels is shown in Fig 4. All the blends show decreasing trend of BSFC with respect to load. This is because the percentage increase in fuel required to operate the engine is less than the percent increase in brake power due to relatively less portion of the heat losses at higher loads [6, 8].

All the blended fuels show considerably less BSFC compared to that of Diesel. Among the CSME blends, B20 CSME showed the least BSFC at all loading conditions. Similarly among the FOME blends B20 showed the least BSFC. This may be due to fraction change in fuel rate which is very small compared to the corresponding change in brake power [2, 4]. As compared to Diesel the CSME B20 showed a decrease in BSFC by 29.18% and 1.33% at 0Nm and 20Nm respectively. And the BSFC of the FOME B20 was decreased by 19.52% and 13.33% at 0Nm and 20Nm respectively when compared to Diesel.

Among these two B20 blends, CSME B20 showed lesser BSFC compared to FOME B20, because the density of B20 CSME is relatively lesser compared to that of FOME B20. Hence, at any given load the quantity of B20 CSME injected into the cylinder is less than B20 FOME.

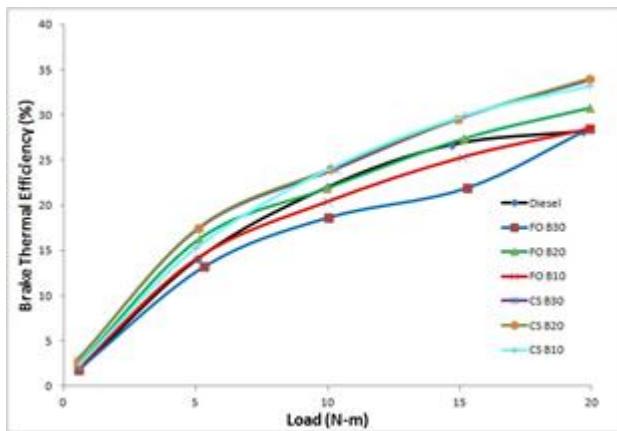


Fig 3: Variation of BTE with Load

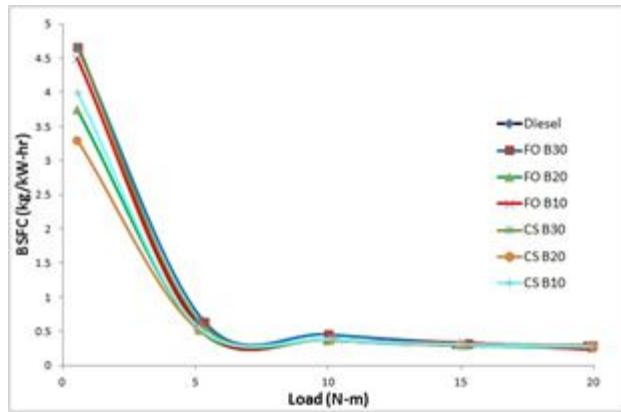


Fig 4: Variation of BSFC with Load

VII. COMBUSTION ANALYSIS

A. Peak Pressure

Fig 5 shows the variation of peak pressures of different CSME blends with load. The Peak pressure is heavily influenced by the delay period. The other influential parameters such as speed, injection pressure and injection timing were kept constant. Hence the peak pressure varied directly with the delay period. Though the delay period decreased with load, the gain in density with respect to diesel made the blended fuels to be injected in more quantity [2, 4, 6, 7]. Hence the peak pressure increases steadily with the load. It is seen from the Fig 5 that the peak pressure of all the blends is higher compared to that of diesel at all loading conditions except FOME B10.

Among the blends of CSME the B30 blend shows the maximum peak pressure at most loading conditions. The CSME B30 showed an increase of 7.93% in peak pressure compared to diesel at 20N-m. Among blends of FOME, the B20 FOME showed the highest peak pressure at almost all loading conditions. The FOME B20 showed an increase in peak pressure by 5.59% than Diesel at 20N-m.

As compared to B20 FOME, B30 CSME shows increased peak pressure by 2.81% at the full load condition. This may be due to lesser density of B30 CSME compared to B30 FOME at any given brake power. Hence, a relatively higher degree of fuel atomization is achieved in case of B30 CSME than B30 FOME [8, 9]. Hence the CSME B30 showed the highest peak pressure at 20N-m compared to all other fuels.

B. Heat Release Rate (HRR)

Fig 6 shows the HRR of various FOME and CSME blends with crank angle at no load condition. No significant change in heat release rates was observed among the blends. This may be due to decrease in calorific values of all blends compared to Diesel.

Fig 7 shows the HRR of various blends of FOME and CSME at part load condition (10 N-m). All the blends except FOME B10 shows an increase in HRR compared to Diesel. The maximum HRR was shown by CSME B10 at 7067 kJ/s whereas the HRR of Diesel was at 6202 kJ/s. At same load CSME B10, B20 and B30 showed greater HRR than Diesel by

13.99%, 9.75% and 11.99% respectively. FOME B20 and B30 also showed higher HRR than Diesel by 11.59% and 11.80% respectively. This significant increase in HRR might be due to clear combustion of the bio-Diesel blended fuels owing to the oxygen molecules present in their molecular structure [7, 8].

Fig 8 shows the HRR of various CSME and FOME blends with crank angle. All blends except FOME B10 shows greater HRR than Diesel. Among the blends, the FOME B30 shows highest increase in heat release rate which was greater by 35.76% compared to Diesel. This may be due to greater fuel supply rate of FOME B30 than Diesel. Also, at 20N-m the naturally aspirant cylinder might have been running low in oxygen. However the additional oxygen content in FOME B30 will result in proper combustion of the same. [7, 8] The CSME B10, B20 and B30 showed an increase in HRR than Diesel by 25.70%, 19.61% and 18.86% respectively.

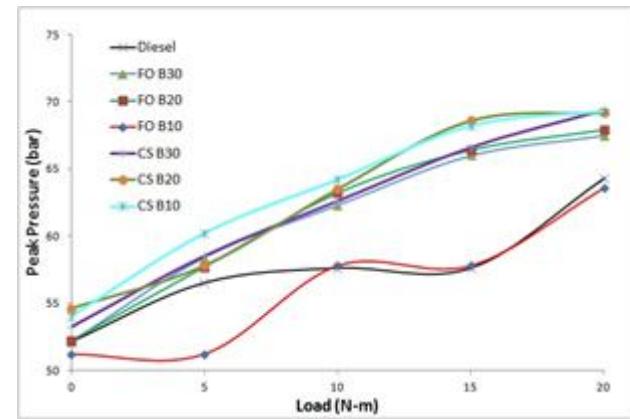


Fig 5: Variation of Peak Pressure with Load

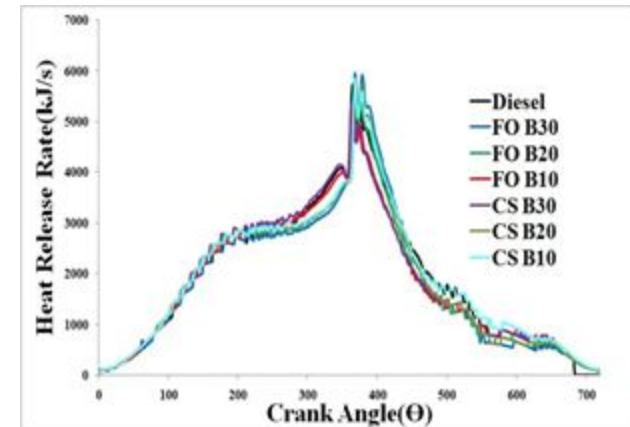


Fig 6: Variation of HRR with Crank Angle at no load condition

VIII. EMISSION ANALYSIS

A. Exhaust Gas Temperature (EGT)

The Fig 9 shows the variation of exhaust gas temperature with load. It was observed that, the EGT increases with increase in load. It is seen that all the biodiesel blends except FOME B20 shows higher EGT than Diesel fuel.

Also among the rest of the blends there is very slight variation in the EGT for as compared to Diesel. This could be

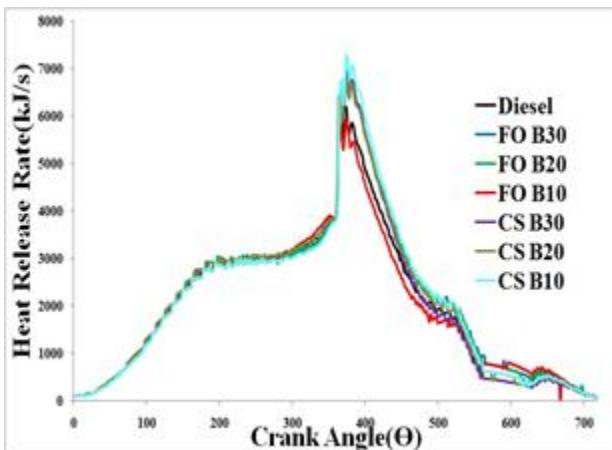


Fig 7: Variation of HRR with Crank Angle at part load condition

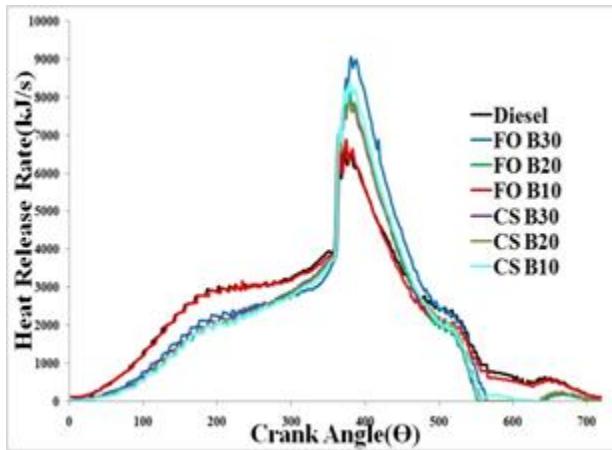


Fig 8: Variation of HRR with Crank Angle at full load condition

due to the same quantity of fuel being consumed per hour for both diesel and blends. Since heat loss to the exhaust on percentage basis was approximately constant throughout the entire load range, same quantity of fuel consumed gave same heat rejection [8, 9]. At full load the FOME B20 showed the least EGT among all other blends at 556.98°C. At the same load CSME B20 showed the second least EGT at 558.18 f u compared to Diesel at 560.7 f u.

B. Oxides of Nitrogen (NO_x)

The variation of NO_x with load is shown in Fig 10. The nitrogen oxides results from the oxidation of atmospheric nitrogen at high temperature inside the cylinder. The majority of the NO_x formed is not due to the nitrogen atoms present in the fuel. Although Nitrogen oxides are considered as major contributor for ozone formation, they are also a reality of operating IC engines. It is observed from the Fig 10 that the amount of NO_x increased with increase in load for all fuels, this is because, with increasing load the temperature of combustion chamber increases which in turn increases the NO_x formation, since it is a strongly temperature dependent phenomenon.

At full load the NO_x emission of FOME B20 and CSME B20 were 1034 ppm and 1058 ppm respectively. This is comparatively lower than Diesel which shows 1086 ppm of NO_x emission at the same brake power. However remaining

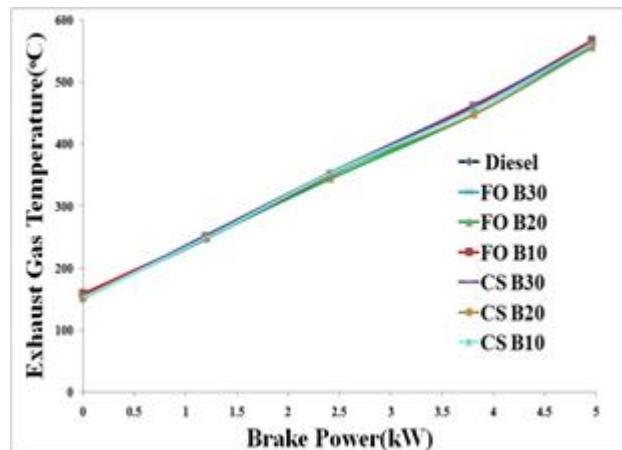


Fig 9: Variation of EGT with Brake Power

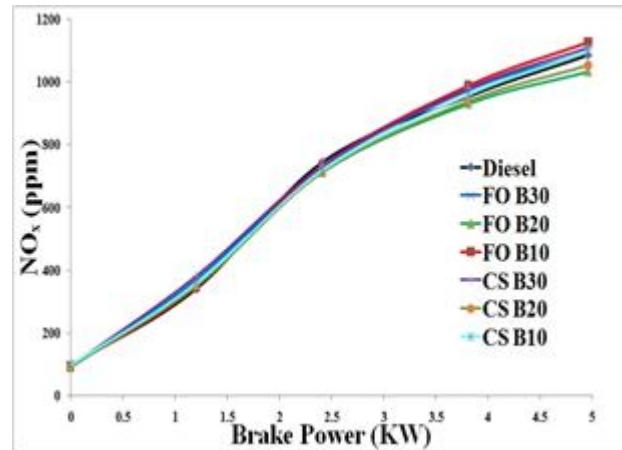


Fig 10: Variation of NOx with Brake Power

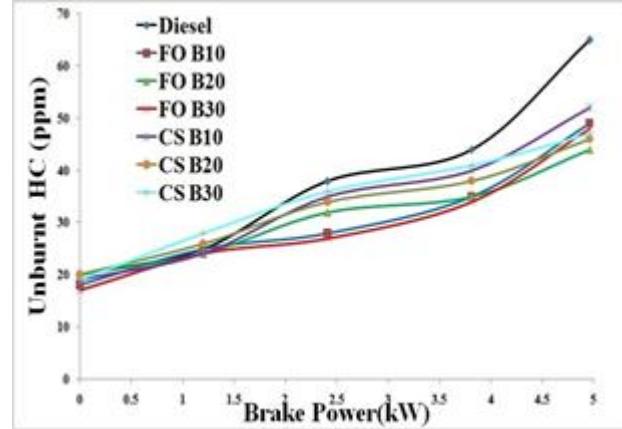


Fig 11: Variation of UBHC with Brake Power

four blends show increased NO_x emission than Diesel at full load. These higher NO_x emissions may be due to higher temperature of the cylinder using biodiesel [8, 9].

C. Unburnt Hydrocarbons (UBHC)

The Fig 11 shows the variation of emission of UBHC of various FOME and CSME blends with load. All the bio-Diesel blends show increased UBHC emission with load. It is observed that UBHC emissions for all biodiesel blends are lower than Diesel. At full load, the FOME B20 shows lesser UBHC emission than Diesel by 32.30%. At the same load, the

CSME B20 shows the second least UBHC emission, lesser by 29.23% to Diesel. Biodiesel is comprised of animal fat and vegetable oil methyl esters, that is they are hydrocarbon chains whose one end of the chain is oxygenated. The presence of oxygen in the fuel promotes complete combustion that leads to lowering the HC emissions. These reductions indicate more complete combustion of the fuel.

D. Carbon Monoxide (CO)

The variation of CO with load is shown in Fig12. The CO is a toxic by-product of combustion of all hydrocarbons. It can be reduced by increasing the oxygen content of the fuel. More complete oxidation of fuel results in more complete combustion to CO₂ rather than leading to the formation of CO [8, 9, 4, 12]. From the Fig 12 it was found that the amount of CO decreased at part loads and again increased at full load condition for all fuels. It was observed that the CO emissions for biodiesel blends were lower than the Diesel fuel. It is also observed that at full load, the FOME B20 shows lesser CO emission than diesel by 47.91%. At the same load, among CSME blends, the CSME B20 shows lesser CO emission than Diesel by 41.66%.

E. Smoke Opacity

The Fig 13 indicates the variation of smoke opacity with load. It was found that the opacity increased with increase in load. The Fig 13 shows that the opacity is lower for all biodiesel blends compared to diesel fuel. At full load the FOME B20 shows the least smoke opacity of 59%. At the same load, the smoke opacity of Diesel was 64.1%. Among the CSME blends the CMSE B20 shows least smoke opacity of 62%. The lack of heavy petroleum oil residues in the vegetable oil esters that are normally found in diesel fuel is the reason for less smoke. Since the biodiesel contains oxygen, there is an increased efficiency of combustion even for the petroleum fraction of the blend [8, 9, 4].

IX. CONCLUSION

The experiments were conducted to study the performance, combustion and emission characteristics of a C.I engine using methyl esters of corn seed oil. Based on the experimental study the following conclusions are drawn:-

- The corn oil and Fish oil is a renewable and important alternative fuels.
- After Transesterification of the oils kinematic viscosity and density are reduced and calorific value is increased.
- The CSME B20 showed the least BSFC at all loading conditions then followed by the FOME B20
- The CSME B20 showed the highest BTE compared to all other blends with an increase of 20.63% at full load condition with respect to diesel. Also all the CSME blends showed higher BTE compared to FOME. But among the FOME blends the B20 showed the highest BTE.
- The B20 blend of FOME and B30 blend of CSME showed the maximum peak pressures among their blends. But the highest peak pressure of 69.3 bars at 20 N-m was attained by CSME B30.

- Marginal increase in heat release rates were obtained at no load condition among all the loads. But CSME B10 and CSME B30 showed maximum heat release rates at 10N-m and 20 N-m loads respectively.

- It was observed from the study that all six blends showed better emission characteristics over Diesel in terms of EGT, NO_x, CO, UBHC, and SMOKE OPACITY.

- The FOME B20 showed least UBHC among all the blends at maximum brake power. The FOME B20 exhibited decreased UBHC over Diesel by 32.30% at this load.

- FOME B20 exhibited least emission of CO and SMOKE OPACITY over Diesel by a significant margin at maximum brake power.

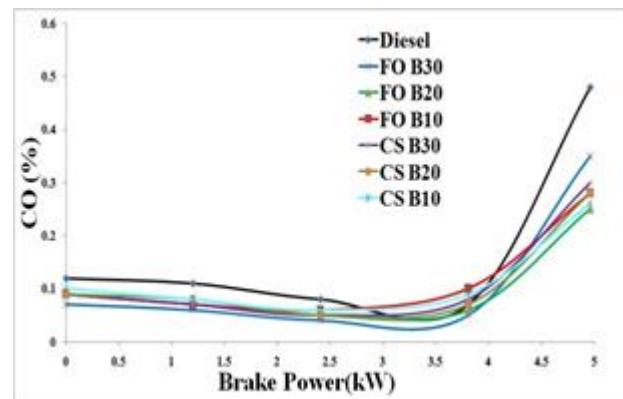


Fig 12: Variation of CO with Brake Power

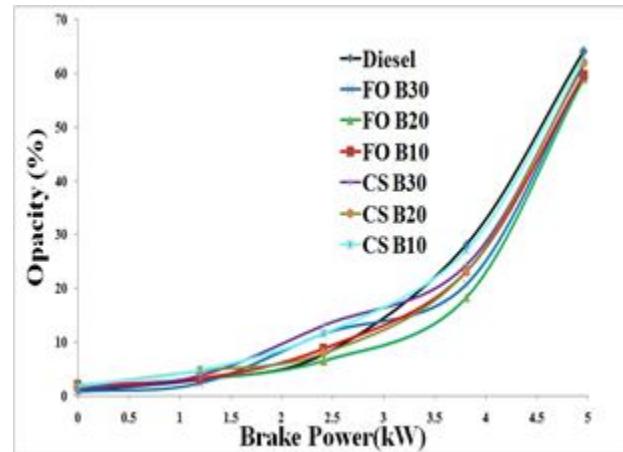


Fig 13: Variation of Opacity with Brake Power

From the above discussions, it can be concluded that marginal improvement in the performance, combustion and emissions characteristics are observed if the blends are properly optimized when a diesel engine is to be operated with the methyl esters of corn seed oil and Fish Oil.

X. NOMENCLATURE

BP- Brake Power

BSFC-Brake Specific Fuel Consumption

BTDC-Before Top Dead Centre

BTE-Brake Thermal Efficiency

B10- 10% biodiesel & 90% Diesel

B20- 20% biodiesel & 80% Diesel

B30- 30% biodiesel & 70% Diesel
 CI-Compression Ignition
 CO – Carbon monoxide
 CSME – Corn Seed Oil Methyl Ester
 DI-Direct Injection
 EGT-Exhaust Gas Temperature at Engine
 FOME – Fish Oil Methyl Ester
 IC-Internal combustion
 NOx – Oxides of Nitrogen
 O2 – Oxygen
 ppm – Parts per million
 TDC-Top Dead Centre
 UBHC- Unburnt Hydrocarbons

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